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ORIGINAL ARTICLE

Coronary sinus catheter placement via left cubital vein for phrenic nerve stimulation during pulmonary vein isolation

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Abstract

Phrenic nerve (PN) stimulation is essential for the elimination of PN palsy during balloon-based pulmonary vein isolation (PVI). Although ultrasound-guided vascular access is safe, insertion of a PN stimulation catheter via central venous access carries a potential risk of the development of mechanical complications. We evaluated the safety of a left cubital vein approach for positioning a 20-electrode atrial cardioversion (BeeAT) catheter in the coronary sinus (CS), and the feasibility of right PN pacing from the superior vena cava (SVC) using proximal electrodes of the BeeAT catheter. In total, 106 consecutive patients who underwent balloon-based PVI with a left cubital vein approach for BeeAT catheter positioning were retrospectively assessed. The left cubital approach was successful in 105 patients (99.1%), and catheter insertion into the CS was possible for 104 patients (99.0%). Among these patients, constant right PN pacing from the SVC was obtained for 89 patients (89/104, 85.6%). In five patients, transient loss of right PN capture occurred during right pulmonary vein ablation. No persistent right PN palsy was observed. Small subcutaneous hemorrhage was observed in eight patients (7.5%). Neuropathy, pseudoaneurysm, arteriovenous fistula, and perforations associated with the left cubital approach were not detected. Body mass index was significantly higher in the right PN pacing failure group than in the right PN pacing success group (26.2 ± 3.2 vs. 23.8 ± 3.8; $P = 0.025$). CS catheter placement with a left cubital vein approach for right PN stimulation was found to be safe and feasible. Right PN pacing from the SVC using a BeeAT catheter was successfully achieved in the majority of the patients. This approach may prove to be preferable for non-obese patients.

Keywords Atrial fibrillation · Left cubital vein · Phrenic nerve stimulation · Pulmonary vein isolation

Introduction

Balloon-based pulmonary vein isolation (PVI) has emerged as a highly effective method for the treatment of drug-resistant atrial fibrillation (AF) [1, 2]. Phrenic nerve (PN) palsy and vascular complications are important complications associated with balloon-based AF ablation [3]. During the procedure, manual monitoring of diaphragmatic excursion caused by superior vena cava (SVC) pacing and fluoroscopic monitoring of diaphragmatic motion from spontaneous breathing are the most common techniques used to avoid PN palsy [4, 5]. However, catheters inserted from the femoral vein for SVC pacing are sometimes dislodged during ablation. To position an electrode catheter in the coronary sinus (CS), venous access is generally obtained through the right femoral vein, right internal jugular vein, or subclavian vein. Although ultrasound guided vascular access is safe, access via these central veins has a potential risk of serious mechanical complications such as arterial puncture, hematoma, hemothorax, and pneumothorax [6–8].

For these reasons, we hypothesized that peripheral vein access to safely and easily introduce a catheter into the CS is desirable and that constant right PN capture from the SVC using a CS catheter would be ideal. The aim of this study

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was to evaluate the safety and feasibility of a left cubital approach for inserting a 20-electrode atrial cardioversion catheter into the CS and to evaluate the utility of right PN stimulation from the SVC during balloon-based PVI.

Methods

Study population

A total of 106 consecutive patients with symptomatic, drug-refractory AF who underwent balloon-based catheter ablation at Toyama Prefectural Central Hospital (Japan) between September 2017 and August 2018 were retrospectively evaluated. PVI was performed for patients who were effectively anticoagulated. Prior to the procedure, the left atrial (LA) thrombus was excluded based on laboratory data and cardiac computed tomography angiography or transesophageal echocardiography. We excluded patients on maintenance dialysis with left upper limb vascular access and those with cardiac implantable electrical devices inserted with left-side venous access because a left cubital approach would be inappropriate for these patients. The Ethics Committee of Toyama Prefectural Central Hospital approved the study. Written informed consent was obtained from all patients before the procedure.

Left cubital approach

The patient placed their left arm on a sideboard at a position slightly detached from their body while the operators stood on the left side of the patient. Puncture of the left cubital fossa was performed using a 20G needle with Seldinger's technique. The median cubital vein, basilic vein, or brachial vein was generally targeted rather than the cephalic vein. Ultrasound guided puncture was performed when these veins are not be visible by inspection. If patients complained of numbness, tingling, excessive, or radiating pain along the nerve, the puncture site was changed to a different part of the left cubital fossa to avoid neuropathy. After successful puncture, a guidewire was advanced through the needle followed by subcutaneous injection of 2–3 ml lidocaine hydrochloride, and a 6Fr sheath was inserted. A 20-electrode atrial cardioversion catheter [20 electrodes (CS 8, RA 8, SVC 4), 2 mm distal marker length, 4 mm electrode length (CS, RA), 1.2 mm electrode length (SVC), electrode spacing: CS 2–2 … –70 mm RA 2–2 … –10 mm SVC 5–5–5 mm, BeeAT; Japan Lifeline Co., Ltd.] was inserted from the 6Fr sheath and advanced to the CS via the subclavian vein and SVC. Contrast venography was performed when BeeAT catheter did not advance smoothly. When venous spasm was observed, a little waiting or nitroglycerin administration was performed. After all procedures were completed, the sheath was removed and hand compression was performed for hemostasis.

Ablation procedures

All balloon-based ablation procedures were performed under conscious sedation. The detailed procedure for cryoballoon ablation (CBA) has been previously described [9]. In brief, a second-generation CB catheter (28 mm; Arctic Front Advance, Medtronic) was advanced to the PV ostium via a 15-Fr steerable sheath (Flexcath Advance; Medtronic, Minneapolis, MN, USA) and then inflated. Contrast medium was used to confirm PV occlusion, and cryoenergy was applied to each PV. The targeted freezing time for each PV was 180 s but freezing was prolonged to 240 s if the nadir temperature was relatively high (above − 40 °C for 60 s). Freezing was discontinued at a luminal esophageal temperature of < 15 °C or when the balloon temperature was − 55 °C or less. Additional freezing was performed if PVI was not achieved after a single session. If PVI was not achieved with additional freezing, touchup ablation was performed using an irrigated CF ablation catheter (Navistar ThermoCool SmartTouch or ThermoCool SmartTouch SF; Biosense Webster, Diamond Bar, CA, USA).

Hot balloon ablation (HBA) was performed using The SATAKE HotBalloon ablation system (Toray industries, Inc., Tokyo, Japan). Detailed explanations of the HotBalloon system have been published [2, 10–12]. A 13-Fr deflectable sheath (Treswaltz, Toray Industries, Inc) was inserted into the LA. The SATAKE HotBalloon was advanced to the PV ostium via a 13-Fr deflectable sheath, and the balloon was inflated with 10–20 ml of contrast medium diluted 1:1 with saline. Contrast media was used to confirm PV occlusion. The balloon size and position were adjusted by injecting a medium volume to achieve complete apposition and complete occlusion of the PV. The target balloon shape for the first radiofrequency application was complete occlusion with slight balloon indentation. A radiofrequency current of 1.8 MHz was delivered between the coil electrode inside the balloon and the 4 cutaneous electrode patches on the patient's back to induce capacitive-type heating in the balloon. The target balloon central temperature was 70 °C in each PV but this value was increased to 73 °C in the LSPV if the PV potentials did not disappear despite complete PV occlusion. The radiofrequency-generated thermal energy application time was 180 s for superior PVs and 150 s for inferior PVs. When luminal esophageal temperature exceeded 39 °C, cooling saline or cooling contrast medium diluted 1:1 with saline was injected into the esophagus. If PVI was not achieved after three HBA sessions, touchup ablation was performed using an irrigated CF ablation catheter.

PN stimulation via 20-electrode atrial cardioversion catheter

During the application of CBA and HBA for the right PVs, high output right PN stimulation was performed from a widely spaced bipole positioned at the SVC using a 20-electrode atrial cardioversion (BeeAT) catheter placed in the CS (poles SVC 1 and 4 at 20 mA with 2.0 ms pulse width and a cycle length of 1500 ms). Before engagement of the RPVs with a balloon catheter, the BeeAT catheter position was adjusted to obtain constant right PN pacing and the diaphragmatic compound motor action potential (CMAP) was recorded (Fig. 1). If constant right PN capture was not obtained using the BeeAT catheter, a 5-French quadripolar catheter was inserted into the SVC from the right femoral vein to stimulate the right PN. Ablation was terminated for any perceived reduction in the strength of diaphragmatic contraction or a 30% reduction in the maximal diaphragmatic CMAP amplitude compared to the baseline [13].

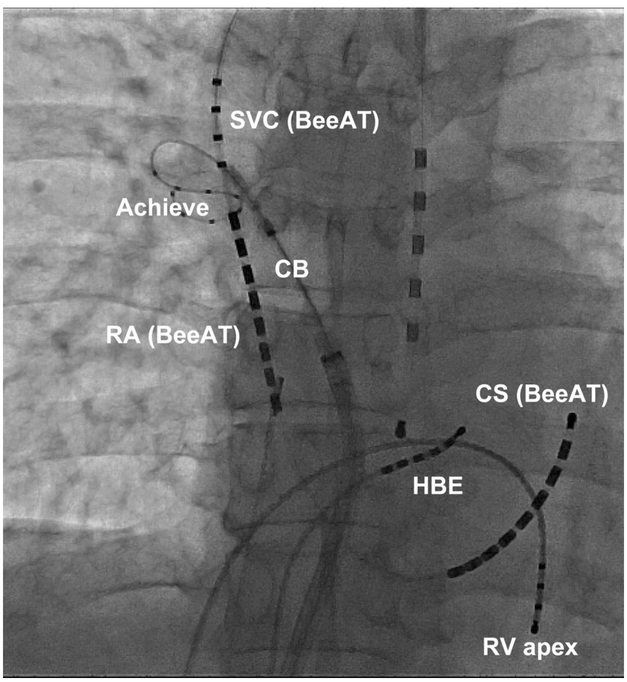

Fig. 1 Representative position of the BeeAT catheter using a left cubital approach. The BeeAT catheter passed more laterally in the SVC and the catheter tip was fixed in the CS. The SVC pacing electrode for the BeeAT catheter was positioned cranial to the RSPV. Before the CB was attached to the RSPV, the BeeAT catheter position was adjusted to achieve constant right PN pacing. Right PN pacing was performed from poles SVC 1 and 4 at 20 mA with a 2.0 ms pulse width and a cycle length of 1500 ms. *CB* cryoballoon, *CS* coronary sinus, *HBE* his bundle electrogram, *PN* phrenic nerve, *RA* right atrium, *RSPV* right superior pulmonary vein, *RV* right ventricle, *SVC* superior vena cava. BeeAT catheter indicates a 20-electrode atrial cardioversion catheter [20 electrodes (CS 8, RA 8, SVC 4), 2 mm distal marker length, 4 mm electrode length (CS, RA), 1.2 mm electrode length (SVC), electrode spacing: CS 2–2 … –70 mm, RA 2–2 … –10 mm, SVC 5–5–5 mm, BeeAT; Japan Lifeline Co., Ltd.]. Achieve catheter indicates octapolar spiral inner mapping catheter specially designed for the CB (Achieve, Medtronic, Minneapolis, MN, USA)

PN impairment was defined as a loss of diaphragmatic movement despite right PN pacing or reduced downward movement of the right hemidiaphragm during spontaneous inspiration. Transient dysfunction was defined as a recovery of PN function by the conclusion of the index ablation procedure. Persistent PN palsy was defined as PN dysfunction that persisted beyond the conclusion of the procedure [14].

Statistical analysis

Statistical analyzes were performed using Graph Pad Prism (GraphPad Software, La Jolla, CA, USA). Data are reported as the mean ± standard deviation. Data were compared using the Student's *t* test and Fisher's exact test to examine the differences between the two groups. All tests were two sided and a *P* value of < 0.05 was considered statistically significant.

Results

The baseline parameters for the patients and procedures in this study are presented in Table 1. The mean LA diameter on transthoracic echocardiography was 38.6 ± 6.4 mm. PVI was performed with CBA for 92 patients (86.8%) and with HBA for 14 patients (13.2%). Although touchup radiofrequency application was necessary for 22 patients, acute PVI was achieved for all patients.

Puncture success rate of cubital approach and incidence of access site complications

The 6Fr sheath was successfully inserted with a left cubital approach for 105 patients and the BeeAT catheter was inserted into the CS for 104 patients. Only one patient required puncture site conversion to the right jugular vein (Fig. 2). There was no patient in whom venous spasm prevented BeeAT from insertion to CS and no venous spasm-related complication was observed.

Tiny subcutaneous hemorrhage was observed in eight patients (7.5%). Major bleeding or clinically relevant non-major bleeding (International Society on Thrombosis and Haemostasis definition) associated with the left cubital approach were not observed [15]. No neuropathy, pseudoaneurysm, arteriovenous fistula, or perforation was detected (Table 2).

Table 1 Baseline patient and procedure characteristics

	Overall	Range or percentage
Patients characteristic ($n = 106$)		
Age (years)	66.5 ± 8.9	45–85
Gender (*n*, % male)	76	71.7
Height (cm)	165.4 ± 9.7	137.2–188.0
Body weight (kg)	65.5 ± 9.9	39.4–105.2
Body mass index	24.3 ± 3.9	18.0–36.3
Antiarrhythmic agents (*n*, %)		
None	31	29.2
Na channel blocker	27	25.4
β-Blocker	27	25.4
Amiodarone	3	2.8
Bepridil	18	17.0
Hypertension (*n*, %)	54	50.9
Diabetes mellitus (*n*, %)	16	15.1
Ischemic heart disease (*n*, %)	10	9.4
Congestive heart failure (*n*, %)	13	12.7
CHA2DS2-VASC (*n*, %)		
0	18	17.0
1	34	32.8
≥ 2	54	50.9
Left ventricular ejection fraction (%)	66.1 ± 10.0	27.0–84.5
Left atrial diameter (mm)	38.6 ± 6.4	25.0–58.0
Paroxysmal AF (*n*, %)	48	81.4
BNP (pg/ml)	89.4 ± 109.2	5.8–604.4
eGFR Cockroft–Gault (ml/min)	67.1 ± 16.0	33.0–149.0
NOAC (*n*, %)	94	88.7
Cryoballoon (*n*, %)	92	86.8
Hotballoon (*n*, %)	14	13.2
1st session (*n*, %)	102	96.2
Only PVI (*n*, %)	76	71.6
Touch up ablation (*n*, %)	22	20.8
Procedural time (min)	137.8 ± 38.2	69.0–310.0

AF atrial fibrillation, *BNP* B-type natriuretic peptide, *eGFR* estimated glomerular filtration rate, *NOAC* non vitamin K antagonist oral anticoagulants, *PVI* pulmonary vein isolation

Probability of constant right PN pacing using BeeAT catheter and incidence of PN palsy during balloon-based ablation

In 89 out of 104 patients (85.6%), constant right PN pacing from the BeeAT catheter was achieved (Fig. 2). Fifteen patients (15/104, 14.4%) required the insertion of a quadripolar catheter from the right femoral vein owing to the failure of constant right PN pacing from the SVC using the BeeAT catheter.

In five patients, transient PN dysfunction was observed during energy application to the RPV and energy application was terminated to avoid deterioration (Table 2). However, no persistent PN palsy was observed.

To identify the risk factors for right PN pacing failure using the left cubital approach, we separated the study population into two groups for right PN pacing success and failure (Table 3). The body mass index (BMI) was significantly higher in the right PN pacing failure group than in the right PN pacing success group (26.2 ± 3.2 vs. 23.8 ± 3.8; $P = 0.025$). However, age, sex, CHA2DS2-VASC, and LA diameter were not statistically different between the two groups.

Discussion

We evaluated the safety and feasibility of a left cubital approach for BeeAT catheter insertion into the CS and the utility of right PN stimulation from the SVC using a BeeAT catheter during balloon-based PVI. Our major findings were as follows: (1) left cubital approach was successful in nearly all cases with no serious access site complications. (2) Constant right PN pacing from the SVC site was feasible in the majority of cases during RPV ablation and the incidence of PN palsy was low. (3) High BMI was significantly associated with right PN pacing failure.

In this study, a left cubital approach was successful in nearly all cases and no serious access site complications were observed. Intracardiac positioning of electrode catheters requires venous access and is generally performed with central venous access. Though the femoral vein approach is widely preferred, other central veins such as the jugular or subclavian veins are used if the femoral veins are inaccessible or unsuitable. Although ultrasound guided vascular access is safe, access via these central veins has a potential risk of serious mechanical complications such as arterial puncture, hematoma, hemothorax, and pneumothorax [6–8]. On the other hand, in an analysis of blood donors, the incidence of needle injuries such as neuropathy and arterial puncture was low with the cubital approach [16, 17]. Although the degree of invasion differs between needle puncture alone and sheath insertion, the left cubital approach was success in almost all cases without serious complications in this study. Venous spasm due to vein puncture or catheter manipulation has been reported [18, 19] and has a potential risk to interfere with catheter manipulation. Nitroglycerin is useful to prevent venous spasm [20]. In the present study, using contrast venography and nitroglycerin when necessary, there was no patient in whom venous spasm prevented BeeAT from insertion to CS and no venous spasm-related complication was observed.

In the majority of cases, constant right PN pacing from the BeeAT catheter was achieved and transient PN impairment during ablation was only observed in a few cases.

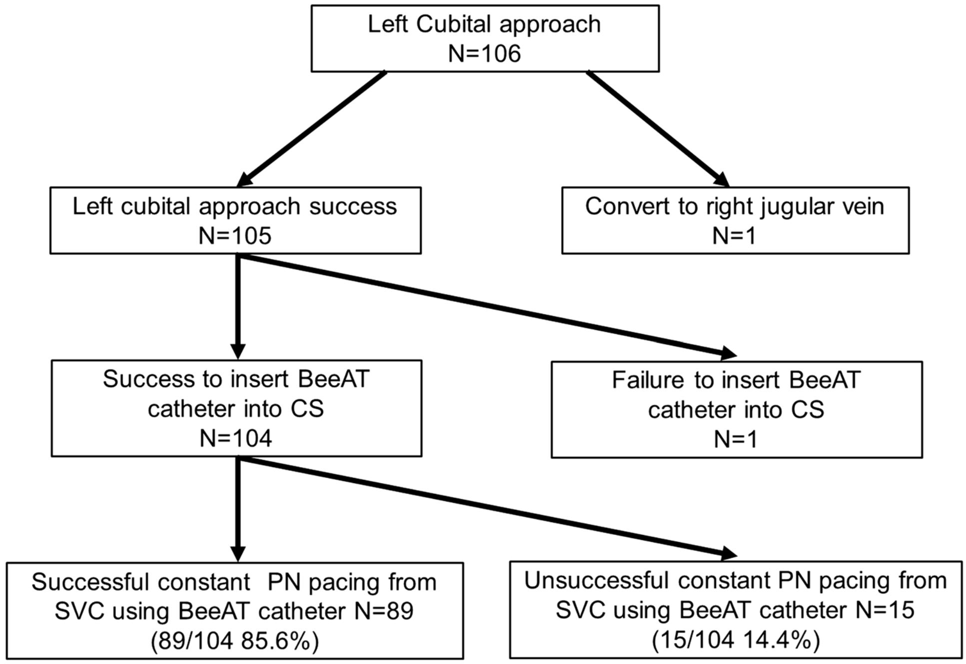

Fig. 2 Patient flow diagram. The left cubital approach was unsuccessful for one patient and positioning of the 20-electrode atrial cardioversion (BeeAT) catheter in the CS was unsuccessful for another patient. *CS* coronary sinus, *PN* phrenic nerve

Table 2 Incidence of access site complications and phrenic nerve impairment

Adverse event	Overall ($n = 106$)	Percentage (%)
Access site complications		
Major bleeding (ISTH definition)	0	0.0
Clinically relevant nonmajor bleed (ISTH definition)	0	0.0
Subcutaneous hemorrhage	8	7.5
Perforation	0	0.0
Pseudoaneurysm	0	0.0
AV fistula	0	0.0
Neuropathy	0	0.0
Phrenic nerve impairment		
Transient dysfunction	5	4.7
Persistent phrenic nerve palsy	0	0.0

ISTH International Society on Thrombosis and Haemostasis, *AV fistula* arteriovenous fistula

Generally, the right PN passes through the right side of the SVC and in front of the pulmonary hilus between the fibrous pericardium and mediastinal pleura within the thorax [21, 22]. Therefore, the stimulation catheter should be placed farther to the right during right PN stimulation from the SVC. Although SVC pacing with a femoral approach is widely preferred, one of the disadvantages of the femoral approach is that the stimulation catheter can sometimes dislodge during the ablation. It is often difficult to differentiate between right PN capture loss due to catheter dislodge and true PN impairment. As a result, ablation may be unnecessarily interrupted due to pseudo PN palsy or true PN palsy may develop and become aggravated while the operator hesitates [5]. With the left cubital approach, the BeeAT catheter passed through a more lateral location in the SVC and the catheter tip was fixed in the CS. As a result, constant right PN pacing from the SVC could be performed in the majority of cases. The utility of PN pacing through a left subclinical approach to avoid ventilator-induced diagram dysfunction was recently evaluated in critical care medicine. In the study, transvenous stimulation activated the diagram in 20 of 23 (87%) right PN capture attempts [23]. Although the stimulation catheter used in the above study was different from that used in the current study, the success rate of right PN pacing from the SVC site was comparable. The incidence of transient PN palsy was approximately 3.5–6.2% with second-generation 28 mm CBA [24, 25], and 1–3.7% with HBA [2, 12]. Permanent PN palsy resulting from CBA is far less common, with an incidence of 0.3% in the FIRE AND ICE trial [1]. In the present study, all patients with PN impairment recovered during index procedures, similar to previous studies.

BMI was significantly higher in the right PN pacing failure group. The incidence of major procedural complications associated with AF ablation has been reported to be similar in normal BMI and obese patients, but the risk of minor procedural complications is slightly higher for the latter group [26]. Although the relationship between BMI and the right PN capture threshold has not been fully investigated, one possible mechanism is that monitoring of diaphragmatic excursion with abdominal palpation might be more difficult in obese patients. Because the right PN capture threshold

Table 3 Risk factors for phrenic nerve pacing failure with left cubital approach

	PN pacing success ($n=89$)	PN pacing failure ($n=15$)	*P* value
Age (years)	66.6 ± 8.9	66.3 ± 8.9	0.89
Sex (*n*, % male)	63 (70.7)	9 (60%)	0.55
CHA_2DS_2-VASC	1.9 ± 1.5	1.9 ± 1.2	0.98
Left ventricular ejection fraction (%)	65.7 ± 10.7	67.9 ± 5.7	0.45
Left atrial diameter (mm)	38.6 ± 6.7	40.4 ± 4.8	0.24
Height (cm)	164.4 ± 9.8	162.7 ± 9.0	0.53
Body weight (kg)	65.5 ± 13.1	69.4 ± 10.5	0.27
Body mass index	23.8 ± 3.8	26.2 ± 3.2	0.025

PN phrenic nerve

at the right subclavian vein position is lower than that at the lateral SVC position [27], right subclavian vein pacing may be warranted in the event of unsuccessful SVC pacing, especially for obese patients.

Study limitations

This study has some limitations. First, this is a retrospective study with a small sample size. Our participants were relatively old Japanese patients with a small stature. A modest increase in BMI affected success rate of right PN pacing. Moreover, at present, BeeAT catheter is available only in Japan. For these reasons, it is unclear whether the present results would be applicable to other populations, especially with a large stature.

Second, because post-procedural ultrasonographic examination was not performed, we cannot exclude the possibility of underestimation of pseudoaneurysm or arteriovenous fistula at the puncture site of the left upper extremity. However, only subcutaneous hemorrhage was observed upon inspection, palpitation, and auscultation.

Third, we performed PN pacing only during right PV ablation. During left PV ablation, fluoroscopic assessment of diaphragm movement with spontaneous breathing was performed. Therefore, we cannot exclude the possibility of underestimation of left PN impairment. However, fluoroscopic assessment of diaphragm movement during spontaneous breathing has been reported to be more sensitive than PN pacing [5] and chest radiographs performed 1 day after the procedure revealed no elevated hemidiaphragm with atelectasis of the ipsilateral lung base in any patient.

Conclusion

CS catheter placement with a left cubital vein approach for right PN stimulation is safe and feasible. Constant right PN pacing from the SVC using BeeAT was achieved in the majority of patients and this approach may be preferable for non-obese patients.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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